

## IMPROVEMENTS ON LOW COST CT SYSTEMS

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### INTRODUCTION

Computed tomography (CT) is a radiographic method that provides an ideal examination technique whenever the goal is to locate and size volumetric detail in three dimensions. Because of the relatively good penetrability of X-rays, as well as the sensitivity of absorption to density and atomic number of matter, CT permits the nondestructive physical and, to a limited extent, chemical characterization of the internal structure of materials. Also, since the method is X-ray based, it applies both to metallic and nonmetallic specimens, solid and fibrous materials, and smooth and irregularly surfaced objects. X-ray CT provides quantitative, readily interpretable data and enables the inspections of structures that are not amenable to any other nondestructive evaluation technique. As a result CT has become well established as an inspection, evaluation, and analysis tool[1].

One example of the application of CT imaging is in determining the effect of defects for cast components. In this study the strength of materials containing defects is determined as a function of the size and location of the defects. CT images can be used to aid in machining of tension samples from a larger component, such that the defect is located at the desired position in the sample. Figure 1 shows CT images for an aluminum tension sample of cross section  $\frac{1}{4}$  inch by  $\frac{1}{2}$  inch. The sample is subjected to tension cycling to determine the yield strength. A large number of such samples are analyzed to determine the full effect of defects for a given material. The use of computed tomography in these studies makes it possible to efficiently collect the necessary data on a large set of well characterized samples.

Most commercial turnkey CT systems are very expensive (~\$1M), which tends to limit applications to high value components. Availability of low cost CT systems would greatly expand the use of this inspection technology. Some additional applications which could benefit from CT measurements include location of shrink porosity before exposure by machining, design of casting dies, soil porosity characterization, packing fraction

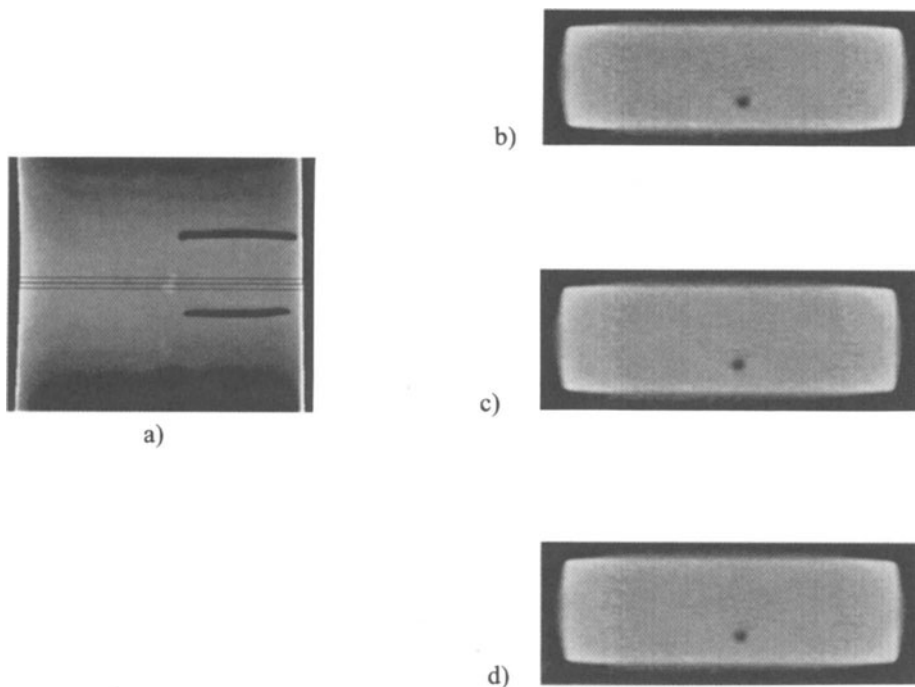


Figure 1. a) Radiograph of an aluminum tension sample, and b,c,d) CT slices at the positions indicated by the lines in a).

characterization, and dimensional analysis of components. In this paper we have evaluated low cost CT systems configured from real-time radiography equipment. Spatial resolution and image contrast are compared for the different systems.

## CT SYSTEM

The CT system used for the purpose of our evaluations is depicted in Fig. 2 and consists of an x-ray generator, a sample positioning system, and a detector system[2]. Two different x-ray generators are used for doing CT work: a standard industrial generator and a micro-focus generator. The standard industrial generator has a large spot size(1.2-3mm) and is used for high power (320kV, 10mA) applications. The micro-focus generator has a small spot size ( $\sim 10\mu\text{m}$ ) and lower power output (200kV, 1mA), and is used in high magnification applications. The detector system consists of a real time detector to convert x-ray intensity to light intensity, a camera and associated lens to convert the light intensity to an electrical signal, data acquisition hardware, and a PC to store the data. In the following sections we present evaluations of different combinations of real time detectors and cameras. The reference system against which we will compare consists of a nine inch image intensifier tube (V.J. Technologies model TH9438HX) and an 8-bit, 640x480 pixel CCD camera (COHU model 4915-2000). Data acquisition is handled by a frame grabber board (Data Translation model DT2867). This board contains a 16-bit buffer into which we are able to accumulate successive image frames to produce an effective 12-bit dynamic range[3,4,5]. Projections are taken at  $1^\circ$  increments and a filtered back projection

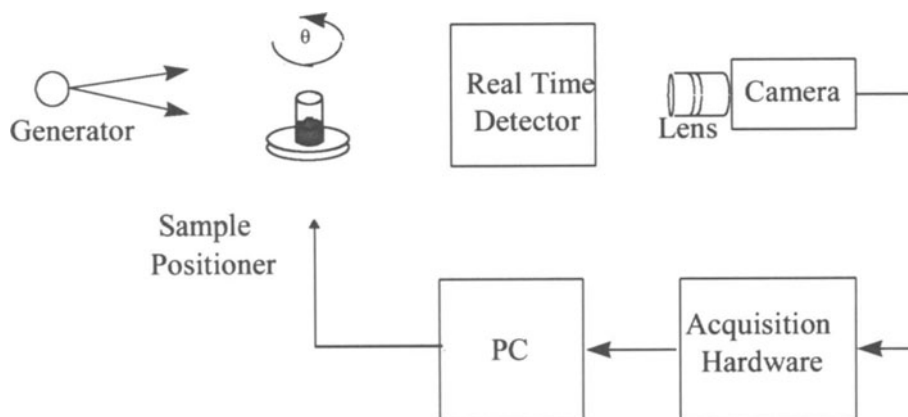


Figure 2. Schematic diagram of the computed tomography hardware.

algorithm is used for reconstruction. The samples used for evaluation of the CT systems are different sized glass beads contained in  $\frac{1}{2}$  inch diameter glass vials. The samples have high contrast in densities, i.e. voids next to high density glass beads.

#### EFFECTS OF TUBE SPOT SIZE AND IMAGE MAGNIFICATION

The combination of spot size of the x-ray tube and magnification of the image plays an important role in the CT results. Three different spot sizes are compared here: 10  $\mu\text{m}$ , 1.2 mm and 3.0 mm. The micro-focus generator was used for the 10  $\mu\text{m}$  spot size. The standard industrial generator with options for 1.2 mm and 3.0 mm spot sizes was used for the others. The detector system described in the previous section was used for data acquisition. The sample was positioned to provide a magnification factor of 1.5, which corresponds to a pixel size of 0.25 mm at the sample. Figure 3 shows the CT images of 1mm glass beads for the three spot sizes. We can clearly see that the quality of the image degrades rapidly as the spot size increases, showing the importance of geometric unsharpness in determining the resolution of CT images.

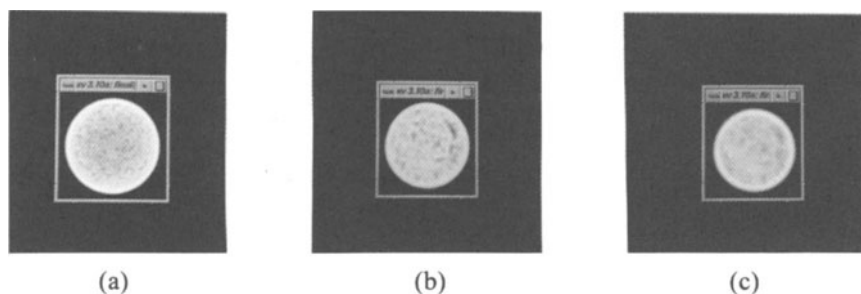


Figure 3. CT images of 1mm glass beads with spot size (a)~10 $\mu\text{m}$  (b) 1.2mm and (c) 3mm.

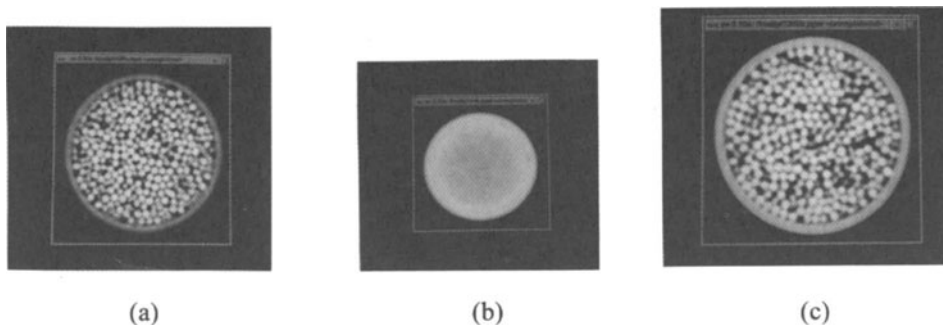


Figure 4. CT images of 1mm glass beads at 5x geometric magnification with spot size of (a)  $\sim 10\mu\text{m}$  and (b) 1.2mm. c) CT image of 1mm glass beads at 3x electronic magnification and 2x physical magnification with  $10\mu\text{m}$  spot size.

By increasing the magnification we can improve the resolution of the image. At a magnification of 5x the pixel size is about 0.07 mm. Comparing Fig. 4a with Fig. 3a, we observe a significant improvement in image resolution for the system using the micro-focus tube. On the other hand, the image using the large spot size has deteriorated. A similar effect of magnification can be obtained by using electronic magnification available on many image intensifiers. Fig. 4c shows a CT image at 3x electronic magnification and 2x physical magnification obtained using the micro-focus tube. As long as geometric unsharpness is not present, image resolution can be improved by using higher magnification. The drawback in using higher magnification is that the field of view, and thus the size of objects which can be imaged, is reduced.

#### EFFECT OF CAMERA AND X-RAY CONVERTER COMBINATION

The image intensifier tubes commonly used for real-time radiography introduce distortions into images and are moderately expensive. Relatively cheap x-ray to light converter screens are available, and they do not distort the images. The drawback is their relatively low light output which requires the use of more sensitive cameras and longer integration times.

We have evaluated a phosphor screen of terbium activated gadolinium oxysulfide viewed by an intensified CCD camera with a 25mm lens. The camera (Photon Technology model IC-100) uses a microchannel plate image intensifier for amplification of low light signals. CT data was acquired at 5x magnification with the micro-focus generator. The spatial resolution is quite good, but the contrast sensitivity is not nearly as good as for the conventional image intensifier. Figure 5a shows the CT image of 1mm glass beads. Figure 5b shows the same image with the contrast stretched to improve the quality of the CT image.

Another type of conversion screen is composed of bundles of fiber optic glass. We have used a 4x4x0.062 inch plate of Lockheed Formula LKH-6 Terbium glass[6] viewed by an intensified CCD camera. Figure 6a shows a CT image of 1mm glass beads at 5x magnification and Fig. 6b shows the same image with the contrast stretched. The results for this fiber optic screen are no better than for the phosphor screen. This indicates that we

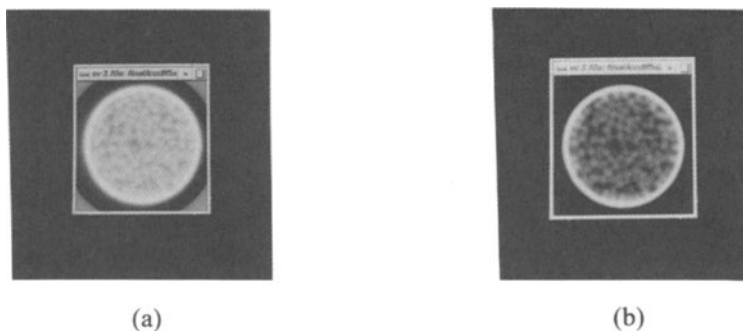


Figure 5. CT images of 1mm glass beads obtained with phosphor screen and intensified CCD camera, (a) original image, (b) contrast stretched image.

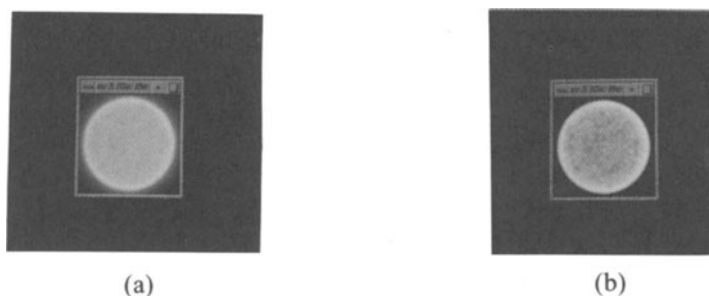


Figure 6. CT images of 1mm glass beads obtained with scintillating glass and intensified CCD camera, (a) original image, (b) contrast stretched image.

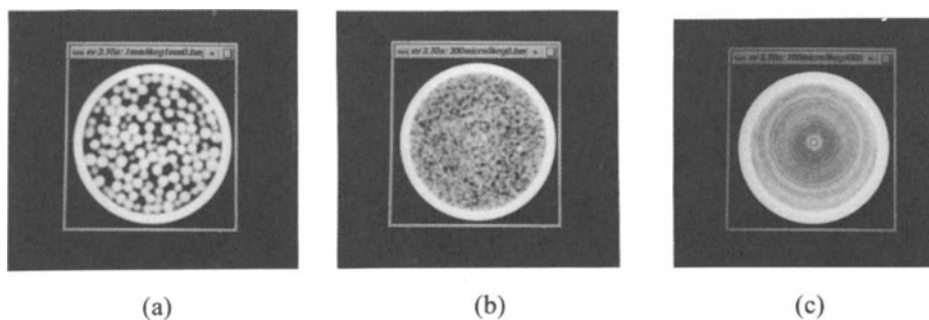


Figure 7. CT images acquired with 8-bit CCD camera for (a) 1mm glass beads, (b) 300 $\mu$ m glass beads, (c) 100 $\mu$ m glass beads.

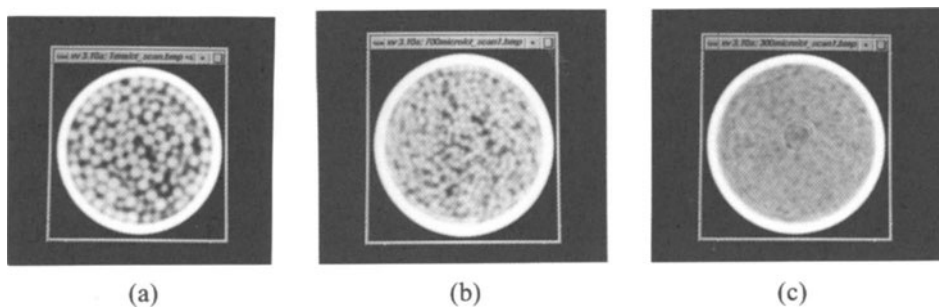


Figure 8. CT images acquired with 14-bit cooled CCD camera for (a) 1mm glass beads, (b) 700µm glass beads, (c) 300µm glass beads.

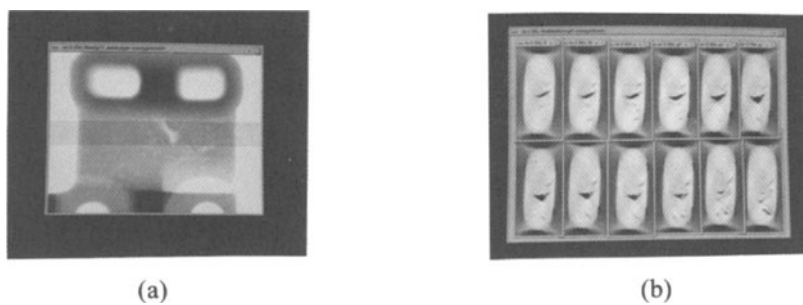


Figure 9. Images of an aluminum casting a) radiograph with lines indicating locations of CT slices shown in b).

are being limited by the resolution of the camera for this field of view. To take advantage of the good spatial resolution of these screens would require selecting a much smaller field of view or using a camera having far more pixels.

Our best results have been obtained with a conventional image intensifier tube and a micro-focus x-ray generator. In Fig. 7 we provide a measure of the spatial resolution showing CT images of different size glass beads. The 300  $\mu\text{m}$  beads can clearly be distinguished, whereas the image of 100  $\mu\text{m}$  glass beads shows significant ring artifacts. These artifacts result from non-uniform response of the different pixel elements in the CCD camera, and are difficult to remove because they have a contrast that is comparable to that of the glass beads.

For comparison purposes we acquired some images using a scientific grade cooled 14-bit CCD camera (Photometrics model CH250) viewing the nine inch image intensifier. Fig. 8a shows the CT image of 1mm glass beads at 5x magnification using a micro-focus generator. CT images of 700  $\mu\text{m}$  and 300  $\mu\text{m}$  glass beads are shown in Fig. 8b and 8c. Comparing Figs. 7 and 8, it is clear that for this application the much more expensive cooled camera is no better than the 8-bit camera coupled with a 16-bit frame grabber.

## VOLUMETRIC IMAGING

Since we are acquiring two-dimensional images with the real time systems, we have the data available to reconstruct three dimensional CT images. Much work has been done on this subject recently[7]. The reconstruction algorithms are very CPU intensive and large amounts of data storage are required for the images. However, many applications don't require a full 3D reconstruction. Much information can be obtained by reconstructing multiple slices of an object. The time of acquisition can be reduced by acquiring multiple slices at the same time. There will be a limited vertical region where the slices can be treated independently without adversely affecting the spatial resolution. Figure 9a shows a radiographic image of an aluminum casting measuring approximately 3x4 inches by  $\frac{3}{4}$  inch thick. The black horizontal lines show the location of CT slices presented in Fig. 9b. The shape of a fairly complex void is mapped out very well in this series of images.

## CONCLUSIONS

We have demonstrated the ability to produce high quality CT images using fairly low cost equipment. A major advantage is achieved by using image magnification with a micro-focus x-ray tube. Although this limits the size of objects which can be imaged, it offers new techniques for studying materials processing in the casting and ceramics industries for example. Although the cheaper converter screens do not seem to provide the same contrast as a conventional image intensifier, they show enough promise to warrant further study with different camera and lens combinations. Application of image processing techniques to these CT images is also being considered as a way to enhance the results.

## ACKNOWLEDGMENTS

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